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Next 1 Page(s) In Document Denied

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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H E L I C O P T E R S

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During the past decade a new type of flying apparatus - - the helicopter - - has received recognition and is finding increasingly-wide employment for both peaceful and military purposes.

As differentiated from airplanes, whose lift originates through progressive movement of a wing placed at a certain angle to the air flow, on helicopters the lifting force is created by a large screw or rotor, which turns on a vertical axis. The helicopter is an apparatus in which the role of the wing is played by a rotor turned by an engine. Abroad the vertolet (Russian word for helicopter - translator) has another name - - helicopter, which, translated literally from Greek, means spiral wing.

The air screw's ability to create a lifting force or, as they say, thrust, regardless of movement in the air and, in particular, when the helicopter itself is motionless in space, determines the main characteristics of the helicopter and its fundamental difference from an airplane.

The helicopter can hover motionless in the air. With an airplane this is impossible. The airplane can stay in the air only by moving at a speed which exceeds a certain critical magnitude. Only movement relative to the air enables it to develop lift. Having lost speed, the airplane falls out of control.

In order to achieve the minimum speed at which its lift is sufficiently large to balance the machine's weight, the airplane must run along the ground. Landing on the ground must be accomplished at considerable speed, somewhat in excess of the minimum. This requires construction of special take-off and landing areas - - airports.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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Thus the airplane is tied to the ground - - to the airport. But for a helicopter, an airport is not required either for landing or for take-off.

Mankind's ancient dream, expressed in the tale of the flying carpet, is most completely embodied in the helicopter. The helicopter is able to rise and land from a mountain top, from a ship's deck, from a forest, from a village street, from the roof of a building, or from a steep cliff - - from any place man can live.

The helicopter is the most universal means of transportation. A train needs a railroad track, an automobile needs a good road. Even an airplane needs an airport. But a helicopter can fly to or from whatever place it pleases.

In addition, the helicopter's ability to stop and hover motionless in the air gives it new advantages as compared with the airplane. The helicopter can perform the functions of an aerial crane, can be used for rescue work, for geological surveying, and for other purposes. The helicopter also has very important significance for warfare.

Undoubtedly people have known for a long time about these interesting and useful capabilities of helicopters. Why, then, did it take so long for the helicopter to be put at the service of mankind?

History of the Development of Helicopter Construction

The history of helicopter development can be divided into several stages. First mention of an apparatus with a vertical screw - a helicopter - is

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

contained in notes made by Leonardo da Vinci which date back to 1483. The initial stage begins with history's first working model of a helicopter, which was built by M. V. Lomonosov in 1754 independently of this (da Vinci) discovery. This first stage continued through a long series of projects, models and even full-sized machines which were not destined to rise into the air. It ended with construction of the world's first helicopter which, in 1907, succeeded in leaving the ground.

Results of the first work on helicopters in one country were little known in other countries, and often the development of new ideas in this field proceeded independently and parallel with each other.

Development of a machine capable of rising into the air became a reality only after the technique of engine building and the development of aviation materials attained a relatively high level. In 1909, the first scientific theory of air screws appeared. It was originated by Russian scientist N. Ye. Zhukovsky. By then the most notable and successful designs became known not only in our country but in other nations as well despite military secrecy. Technical progress in helicopter development, just as in many other fields, became a world-wide phenomenon.

One can not say that designers, scientists or inventors copied something done in another country. The success of a new or, perhaps, of a long-known fundamental plan which is employed under new technological conditions is sometimes achieved unexpectedly be a particular designer although the scheme has drawn the attention of engineers for quite a while and has had followers in different nations of the world.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

The work of a large number of scientists and designers who achieved free helicopter flight should be included in the second stage of helicopter development.

In 1907 the French designers Breguet and Riche built a four-rotor helicopter which was the first to leave the ground (Illustration 1).

In the United States in 1923 a passenger was lifted into the air for the first time in a helicopter designed by (de) Bothezat. The first world altitude record of 18 meters was established in 1930 in an Italian (d') Ascanio coaxial helicopter.

In Russia, on the basis of scientific work done by N. Ye. Zhukovsky with regard to helicopter screws in the period from 1890-1910, a group of his students headed by B. N. Yuriev - who later became an Academy member - built a single-rotor helicopter with a 32 horsepower motor, in 1912. Breaking of the rotor shaft and the beginning of the World War prevented the completion of this work. However, in the configuration of this first helicopter of B. N. Yuriev we recognize the basic plan of the single-rotor helicopters that are most widely employed in the world today - both Soviet types built by the author (Mil) and American helicopters built by Sikorsky, Bell and others.

B. N. Yuriev was not able to return to this work until 1925, since in the first years of Soviet power Zhukovsky's students were busy with construction of the scientific establishments of the Central Aero-Hydrodynamic Institute (TSAGI), with the building of schools, and with the development of aviation matters generally. In the following years, A. M. Cheremukhin, K. A. Bunkin, A. M. Izakson, I. P. Bratukhin, and others took part in helicopter work. The

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

TSAGI EA-1, built under the direction of A. M. Cheremukhin and piloted by him, reached an altitude of 600 meters in 1932 and remained in the air for 18 minutes. This was an outstanding achievement for its time. The official altitude record, established three years later by the new coaxial Breguet helicopter, was only 180 meters.

Besides those named, many designers built helicopters; however, they had even less success. Helicopters of that time were awkward; piloting was complex; and the machines were dangerous if there was engine failure. It was impossible even to think of flying these craft beyond the boundaries of the airport.

The Origin and Development of Autogiros

During the years of the first World War, airplanes equipped with guns and bombs became considerably heavier. The loading per square meter of wing surface increased. Such planes became very susceptible to loss in speed. An error by the pilot in letting his speed drop below what was permitted instantly put the plane in a spin - an uncontrollable spiraling fall. More often than not, the spin resulted in catastrophe and human victims. The spin became known as the scourge of aviation in those years.

A crash of this type with a new experimental plane led the Spanish designer Juan de la Cierva to invent a wing which never loses speed of movement in the air.

He suggested that the wing be replaced by a large rotor, leaving all the remaining parts of the plane unchanged. The shape of this rotor was chosen so that it was gyrated by the inflowing air stream, creating lift at any

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

flying speed. Even vertical descent was not frightening to this type of machine, which received the name autogiro. The lifting force which develops during the self-turning or, as they say, autorotation of the rotor supports the autogiro, making its descent in this case slow and even, like a parachute.

The autogiro became a new member of the family of rotary wing flying machines to which the helicopter also belongs. It differs from the helicopter only in that its forward motion, like that of an airplane, is provided by a tractor propeller.

Shown in Illustration 2 is the interaction of the forces which develop and attend the flight of an airplane, autogiro and helicopter.

Cierva's idea quickly found practical application. The young engineer began to work in England and built several designs which were put into quantity production. The best known of these was the C-30 autogiro.

A few years later, Soviet designers also built a number of original autogiros. Several of them considerably surpassed foreign models in power and size. The first Soviet autogiro, the KASKR-1, was built in 1928 at the facilities of the Osoaviakhim (Society for Promotion of Self-Defense and the Aero-Chemical Industry) by engineers N. I. Kamov and N. K. Skrzhinsky. Then the TSAGI 2-EA autogiro was built in the Central Aero-Hydrodynamic Institute by engineers A. M. Cheremukhin, V. A. Kuznetsov, I. P. Bratukhin and others. The A-4, an improved modification of this autogiro, was manufactured in small experimental numbers. Later, an entire series of (autogiro) designs developed one after the other by V. A. Kuznetsov were built: the A-6, A-8 and A-14.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

In 1937, the A-12 autogiro-fighter, built according to the plans of N. K. Skrzhinsky and M. L. Mil, attained a speed of 260 kilometers per hour at a height of 5,000 meters. This speed has not been surpassed by helicopters even today.

The A-7 autogiros built by N. I. Kamov (produced by the Central Aero-Hydrodynamic Institute in 1934 and built in small numbers in 1940) took part in our forces' combat operations during the Great Fatherland War (World War II). Engineer A. M. Izakson directed the special design section of the Central Aero-Hydrodynamic Institute in which the previously-mentioned autogiros and the 3EA, 5EA and 11EA helicopters were developed in the period from 1930 to 1937.

A New Stage in Helicopter Development

Building a dependable and sufficiently-perfected autogiro was simpler than building a helicopter. First of all, the autogiro did not require a complicated mechanical drive since its lifting rotor turns freely from the effect of the incoming air flow. It was easier to make such a rotor sturdy, controllable and long-wearing. This was achieved by means of hinged attachment of the blades to the hub.

With such attachment, the blade acquires about the same freedom of movement with regard to the hub as our arm in the shoulder joint. The lifting force acting upon a blade cannot break it. It only deflects the blade upward, but the blade retains great centrifugal force from the extreme sweep.

Autogiro design gradually changed. To decrease the take-off run, they began to turn the lifting rotor forcibly -- off of the motor. Finally autogiros began to take off without any run at all -- by leaping. Such an autogiro - -

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

the C-40 -- was built in 1938 in England by designer Cierva. An autogiro which took off without a run was built in the USSR in 1943.

Now literally a single step separated the autogiro from the helicopter. And designers made this step simultaneously in several countries: in Germany, America and the Soviet Union.

The results were not slow in making themselves known. As soon as they adapted the autogiros' "head" -- the hinged lifting rotor and control -- to helicopters the latter begain to fly confidently. The new lifting rotor solved not only many problems of stability, controllability and durability but also solved the main problem -- safety in flight. Motor failure no longer was frightening for a helicopter: its lifting rotor changed over to an autorotation regime and created sufficient lift for a safe landing.

Thus with the help of autogiros, helicopters in the years 1937-1940 entered a new stage in their development -- a time of technical maturity.

The first such machine was a helicopter designed by the German professor Heinrich Focke -- the FW-61 -- built in 1937. Up to this time the Focke company manufactured Cierva C-19 autogiros under license. The new helicopter had the narrow, slightly-curled blades characteristic of autogiros with the horizontal and vertical hinges customary for autogiro rotors and also with a system of direct control by means of cyclic change of the blades' pitch, which was first used in 1935 on the Hafner autogiro. This control system represented application to blades with hinged fastening of an auto matic swash plate for stiffly-fixed blades (described as early as 1909 by

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

B. N. Yuriev and used previously on helicopters developed by the Central Aero-Hydrodynamic Institute). The problem of neutralizing the reactive moment (torque) was originally solved on the Focke helicopter (illustration 3). Its two lifting rotors, located on each side of the fuselage, had different rotating directions.

The qualitative leap in helicopter construction occurred thanks to the generalization of experience in creating the autogiro lifting system with experience in helicopter building. The maximum speed for helicopters up to this period did not exceed 40 kilometers per hour. The new rotor and control system permitted helicopter flying speeds to be increased sharply.

Thus, for example, the FW-61 helicopter reached a ceiling of 2,429 meters, a flying speed of 122.5 kilometers per hour, and a maximum endurance of 1 hour 22 minutes. These were flight performance figures which enabled one to think about the practical utilization of helicopters.

In the United States in 1938-1939, the famous aviation designer Igor Sikorsky again turned to work on the helicopter. Sikorsky, once a student in a Russian aviation school and the builder of the first four-engine "Ilya Muromets" bombers, emigrated from Russia in 1917. Utilizing the autogiro rotor design, Sikorsky in 1938 built the single-rotor VS-300 helicopter. In 1942 a small number of R-5 helicopters were built. An improved version of the R-5 received the designation S-51.

And, finally, in 1939-1940, the "Omega" helicopter designed by I. P. Bratukhin appeared in the USSR. It also demonstrated good flying performance which qualitatively excelled that shown by previous helicopters. This helicopter

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

was of transverse (lateral) arrangement but, as differentiated from the Focke machine, was a twin-engine version (Illustration 3).

Helicopters began not only to rise from the ground but even to fly in the full sense of the word. These first helicopter successes brought forth, especially in the United States, a large number of followers. Like soap bubbles, helicopter manufacturing firms rose up. Many inventors and enterprising people obtained support from large American companies which wanted to invest their money in the new business. In 1944-1945 in the United States alone over 17 helicopter-manufacturing firms were counted. Most of them ended in failure since the complex problem (of helicopter construction) required deep knowledge and tenacious work. But even so, several firms achieved success. Thus, in particular, success came to the young engineer Arthur Young, who developed an arrangement which increased the dynamic stability of a two-bladed lifting rotor. With financial support from the American gun king Bell, he built a small two-place, single-rotor helicopter -- the Bell-47.

During the same years, designer Piasecki came into prominence in the United States. He first built a small single-rotor machine and then, using the lifting rotor tested on it, he put together a twin-rotor helicopter of longitudinal (tandem) arrangement. In Russia this arrangement was worked out in detail as early as 1913 by Sorokin.

Engineer Stanley Hiller built a small coaxial helicopter. Thanks to effective flights and to advertising, his long-known design plan again found followers in all the countries of the world. Later Hiller built a small single-rotor helicopter which found practical application.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

At the same time, the first three successful helicopter designs were developed (further). Thus Focke in Germany in 1943 built the Fa-223 helicopter with a 1,000-hp. motor which achieved excellent flight performance. This was again a single-engine, dual rotor machine of transverse arrangement with the rotors carried on cantilevers. Our armed forces captured several of these quantity-built machines in Berlin in 1945 while they were being assembled. But they were destined never to go into practical use.

I. P. Bratukhin developed his version of a twin-engine helicopter with transverse arrangement. He built the "Omega" helicopters with 500-hp. AI-26GR engines and, finally, the B-11 helicopter with two 570-hp. engines. These helicopters were demonstrated at the air parades in Moscow in 1948 and 1949.

The successful utilization in helicopter construction of the lifting system developed for autogiros naturally led to a shift of autogiro designer teams into this field.

The famous Austrian autogiro designer Hafner came forward in England in the capacity of chief designer for the Bristol company and in 1947 built the Bristol-171 helicopter. Hohenemser, the German theorist in the autogiro field, directs work on helicopter construction for the British Fairey company. The famous American autogiro designers LePage, Kellett and others also built a number of helicopter designs.

Autogiro builders in our country also went to work on helicopters. Designer N. I. Kamov in 1945 began to plan a coaxial helicopter known under the name

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

of "the flying motorcycle." This craft was built by 1949 and shown in the air parade. In 1946, the famous airplane designer A. S. Yakovlev turned to work on helicopters. The youngest (Russian) helicopter design bureau, headed by the author (Mil), was organized at the end of 1947.

Thus the front for helicopter design work was widened and strengthened. As a result, in a ten-year period (1937-1947) a large number of helicopter designs having acceptable flight performance were built throughout the world.

During these years questions were solved regarding selection of the fundamental design arrangement from the standpoint of getting greater weight efficiency, achieving the required flying performance, and working out the problems of helicopter stability and controllability.

However, little was accomplished to ensure practical utilization of helicopters. Helicopter construction, after having overcome its childhood diseases of the first period (poor weight efficiency, instability and poor controllability), was hit by two scourges — vibration and fatique phenomena. These difficulties appeared in the mature age of helicopters, that is, when helicopters began to fly for a long time — for hundreds of hours and more.

The Struggle for Helicopter Construction Dependability

Large amounts of oscillation or, as it is called, vibration, brough a multitude of disappointments to the designers of the first helicopters. Not infrequently this shaking in the machines was so strong that flight became impossible. It seemed that the helicopter was not moving along a smooth aerial road but along cobblestones.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

It wasn't easy to get rid of this shaking. The inducer of this vibration is in the helicopter itself -- in its lifting rotor. During forward flight, a constant centrifugal and variable lifting force acts upon each rotor blade. As is known, the magnitude of the lift depends on the speed with which the blade cleaves the air flow. Therefore, it is greater when the blade moves toward the flow and less when the blade goes "down stream". Although the flywheel movement also partially reduces the difference between the forces which act from the right and left, equalizing the moment from their relatively horizontal hinges, even so there remains a certain unequalized fragment. Thus even the overall lift of the rotor is not constant as it is with an airplane wing. Its magnitude changes periodically, even though insignificantly, three times per revolution on a three-bladed rotor, four times per revolution on a four-bladed rotor, etc. These changes in magnitude of the lifting force are transmitted through the rotor hub to the helicopter's entire frame, causing it to shake.

Each structure and individual part has its own natural oscillations whose frequency depends on the rigidity of construction, its shape and load distribution.

Take a T-square for example. First press it to the table and then bend and release its loose end. The T-square begins to vibrate fast. These vibrations gradually die out, but their frequency in numbers per second will always be a constant magnitude no matter how often we repeat the experiment.

This is the T-square's frequency of natural oscillation.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

If we now turn the T-square so that its cross bar hangs loose and repeat the experiment, then, with the previous length of free T-square end, its natural oscillations become considerably less frequent. The load on the end -- the cross bar -- slows down the natural oscillations. It is not difficult to be convinced that a thicker -- more rigid -- T-square vibrates more frequently than a thinner T-square. A shorter -- that is, a comparatively more rigid free end -- vibrates more frequently than a longer free end.

Different helicopter designs also have their frequencies of natural oscillations. A helicopter of transverse design with heavy engines and rotors placed on the ends of the wing is similar to the end of a T-square with the cross bar. As with the latter, the frequency of natural oscillations of helicopters of this design is low. The fuselage of a helicopter of longitudinal design is thicker than the wing of a helicopter of transverse design. Therefore, despite the fact that engines and rotors are located on the ends of such a fuselage, the natural frequency of its oscillations is comparatively high. The greatest natural frequency of oscillations for a structure and, consequently, the greatest rigidity, is found in a single-rotor helicopter. All of its main loads are compactly located in the middle, and the tail and nose are lightly loaded.

A helicopter rotor, making but 170-200 revolutions per minute, conceals within itself a menacing danger. It is the source of low frequency vibrations close to the frequency of natural oscillations of a structure with little rigidity. In such a situation, the resonance of the structure causes large vibrations and stresses. The resonance is not only unpleasant to the passengers and crew but can, in addition, lead to quick disintegration of the helicopter.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

But even if the design of a helicopter is successfully chosen and has, overall, sufficient rigidity the designer even so must be wary of vibration by any of its parts. The control rods, transmission shafts, the fuselage -- all of these have their frequencies of natural oscillations. Therefore, the designer, having previously decided upon the number of revolutions for the lifting rotor, in varying the geometric dimensions and shape of parts, chooses them so that they will not resonate in flight.

Finally the vibrations too, were mastered. And now, when the first helicopters had already survived their "childhood sicknesses"--insufficient power, instability in flight, and shaking-- and had passed tests and gone into practical operation, a new and frightening ailment awaited them: fatigue phenomena which develop in structural elements.

The changing aerodynamic force in flight bends the hinge-fastened blade millions of times. Up, down, up, down -- it constantly bends it and unbends it. Metal withstands changing stresses considerably more poorly than it withstands a constant stress. It is only necessary to exceed a certain, comparatively low limit and the metal fast develops microscopic cracks which in turn lead to quick destruction of parts. As they say, the metal fatigues. Everyone has surely used this characteristic of metal in ordinary living. Who has not tried to break a metal wire, even one only a bit thicker than a thread, with his hands? One has only to bend the wire several times first in one direction and then in the other and it breaks very quickly.

Until comparatively recently, helicopters were very short-lived machines. In operation they had frequent accidents, the cause of which remained unknown until the effect of fatigue, which develops in metal with changing

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

stresses, was discovered and studied.

Thus, for example, the main beam of a blade -- a steel longeron -- is destroyed by a constant, singly-applied stress if for each square millimeter of its cross section there is a force of 120 kilograms. But it is only necessary to reverse the direction of the force periodically and the same beam will be able to withstand a stress of only 30 kilograms per square millimeter for an extended period of time.

If a wire is notched, then with a varying bending motion it is broken especially fast and exactly at the point of the notch. The role of such a notch can be played by any hole drilled into the steel longeron of the blade even though it is only to fasten the skin to it. In this case the longeron is able to withstand a changing stress of not 30 but only 10-12 kilograms for each square millimeter over an extended period of time. This is one-tenth as much as with a constant stress!

What could be used to replace the bolts and rivets? How could the parts be fastened together without making use of joint holes? Long seamless tubing of varying gage and special glues which securely join metal parts are being widely introduced in helicopter construction. There also were developed structures for blades made of one-piece, pressed Duralumin shapes which have the form of the nose part of the blade section with a glued on light, metal rear section. Perfected technology and careful finishing of the surface also abated to a considerable degree the effect of fatigue on a helicopter's metal structures. All this, in conjunction with knowledge of active, variable stresses and the laws of metal fatigue now permit helicopter rotors to be made with absolute dependability.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Having provided for the durability of all parts, how long will a helicopter operate? In order to answer this question, a helicopter is subjected to tests which differ greatly from durability (strength) tests on airplanes. On the latter the designer is entirely satisfied when he has determined the load which will destroy a structure, as, for example, a wing. Thus a wing is considered safe if this load exceeds by a certain number of times the forces which act upon it in flight.

To a helicopter builder, such a test doesn't provide any assurance of his machine's strength. The structure may withstand very well a large load applied only once but be destroyed by a load incomparably less which is applied repeatedly. Therefore, helicopters are subjected to stresses which are small but are repeated millions of times.

During such tests the helicopter is tied down on strong steel cables while the engine operates successively at different power regimes from cruising to take-off. However, even these tests do not fully reproduce the operating conditions of the blades in flight. They are subjected to still more tests on a stand. Only when the steel parts withstand 10 million cycles at specific stresses and the Duralumin parts can withstand more than 30-40 million cycles is the structure considered to be strong and suitable for long service.

Thus, by overcoming one difficulty after another, the helicopter entered the ranks of operating aircraft.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Among the dozens of named and successfully-flown helicopters which were adaptable for practical use, very few succeeded in going all the way along this road to its end--showing lack of vibration, reliability and safety in flight, and sufficient operating time between overhauls to be considered serviceable enough for practical utilization.

The first such helicopter in our country was the Mi-1, built in 1948 and put into use in 1950.

The Mi-1 helicopter is built on the single-rotor plan with one tail rotor. The helicopter is equipped with an AI-26V engine designed by A. G. Ivchenko and providing 570 horsepower for take-off.

Thus the single-rotor design survived its second birth in our country. Developed by B. N. Yuriev as early as 1912, it served as the basis for building the first Soviet helicopters in the 1930s. We returned to it once again in the 1940s when this arrangement was the logical continuation of Russian work on autogiros.

In our design team, which built the Mi-1 helicopter and then the Mi-4, we should mention N. G. Rusanovich, G. V. Kozelkov, V. A. Kuznetsov, A. K. Kotikov and A. Z. Malakhovsky. In testing and perfecting the Mi-1, great credit belongs to pilots M. K. Baikalov, G. A. Tinyakov and V. V. Vinitskom.

Besides the design bureau, a whole group of scientific institutes and manufacturing plants took part in the building and perfecting of these helicopters.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

The Mi-1 helicopter both from the standpoint of speed and flying altitude far outstripped foreign single-rotor helicopters, having demonstrated with full gross weight and equipment a maximum speed of 205 kilometers per hour, a practical ceiling of over 5,300 meters and a static (hovering) ceiling of 3,300 meters.

In 1951 at the Tushino air parade, thousands of Moscow citizens observed groups of quantity-produced machines of this type in flight.

Quantity-produced American helicopters appeared only a few years earlier: the Sikorsky S-51, Bell-47 and Piasecki PV-3. If the British Bristol-171 is added here, then we have all of the helicopters worthy of mention which first found practical use (Illustration 4) although experimental designs in this period were numbered by the dozens.

These most successful and perfected helicopter designs found considerable acceptance for the first time in aviation history in the period 1945-1950. They were single-engine, 2-4 place machines with engine power of up to 600 hp. Four of them were built according to the single-rotor plan and only one according to the dual rotor, longitudinal arrangement. Basically, all of these machines were intended to perform some military task. They only found a place in civilian use by virtue of their military development and introduction.

Single-Rotor Helicopters

The use of helicopters during the war in Korea in 1950-1953 gave new impetus to the development of helicopter construction.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

The Americans' barbarous employment of the atomic bomb at Hiroshima in 1945 forced even the U. S. itself to plan methods of landing troops from ships under conditions of atomic weapon counteraction. Thus the idea was born of creating special landing helicopters which permitted troops to be set ashore directly from the ships to points behind the line of coastal defenses.

Military training exercises for landing operations using Piasecki helicopters, each of which accommodated six soldiers, were carried out in the United States as early as 1948. Then the Sikorsky S-55 helicopter was designed and built especially for landing and transport purposes. It was able to carry 5-6 men besides the crew. This very successful machine was at the time the largest single-rotor helicopter, having a gross weight of 3,400 kilograms and a lifting rotor diameter of 16 meters.

At the end of 1951 at Inchon (Korea) these helicopters were used for the first time to land a battalion of marines. This played a significant role in the progress of the operation.

Only a year after this event, at the end of 1952, there appeared in quantity production in the USSR the new Soviet Mi-4 landing and transport helicopters. These helicopters doubled the capability of the S-55s from the standpoint of gross weight, engine power and load lifting capacity. With a gross weight of 7,200 kilograms, a 1,700-hp. ASh-82V engine designed by A. D. Shvetsov and P. A. Soloviev, and a rotor diameter of 21 meters, the Mi-4 is able to carry a normal load of 1,200 kilograms and, in the transport version, 1,600 kilograms. Possessing equipment for blind and night flights, an anti-icing system and hydraulic servo-control, the Mi-4 helicopters have no equals and

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have left foreign helicopter construction several years behind. They have again brought our country to leading positions in this field of engineering. In 1956, pilot R. I. Kaprelyan established new world records in a Mi-4 helicopter (Illustration 9, pages 20-21), setting a speed mark of 187.5 kilometers per hour and an altitude mark of 6,017 meters with a useful load of 2,000 kilograms.

The Mi-4 helicopter has a special cargo hatch which permits loading a GAZ-69 (Jeep), a "Pobeda" passenger car or artillery weapons inside the fuselage (Illustration 5). The Sikorsky S-55 and S-58 helicopters do not have such loading facilities although the latter essentially duplicates the dimensions of the Mi-4 (Having engine power of 1,530 hp. and a weight of 5,800 kilograms). Only very recently was the experimental, twin-engine Sikorsky S-56 built which also has a loading hatch that considerably increases the helicopter's tactical value (Illustration 6).

Helicopter of Other Designs

We will now pause to mention the development of helicopters of other designs. Experience in building and perfecting single-rotor helicopters opened broad possibilities for building helicopters with other designs. The main lifting system -- blades, rotor hub, automatic swash plate and control mechanism -- which are made for single-rotor helicopters can be employed without alteration for building any dual-rotor design combination.

At the air parade in Moscow in 1955, the largest quantity-produced helicopter in the world -- the Yak-24 designed by A. S. Yakovlev -- was demonstrated for the first time. In 1956 pilots G. A. Tinyakov and E. F. Milyutichev established a world record in this helicopter by lifting a

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4,000 kilogram load to an altitude of 3,000 meters. These (Yak-24) helicopters use the lifting system employed in quantity-built Mi-4 helicopters.

The concept of using the lifting system perfected for the single-rotor PV-1 helicopter for the dual-rotor, longitudinally-designed PV-3 was put into practice for the first time in the United States by designer Piasecki. This craft was subsequently developed successfully for quantity production and served as the basis for building the larger, dual-rotor, but also single-engine H-21 machine. Construction of new machines of longitudinal design, but in a twin-engine version with the engines carried at the ends of the fuselage, encountered great difficulties. Such difficulties were experienced in particular in England by the Bristol company which in 1950 built the dual-rotor Bristol-173 helicopter based on the single-rotor Bristol-171 helicopter. Six years of tenacious research has failed to bring success. After construction and successive modifications in which the controllability and stability of this helicopter were improved and a solution was also found to the ground resonance difficulty (which increases a helicopter's swaying on its landing gear -- induced by the oscillation of the rotor blades around their vertical hinges) it became apparent that a substantial increase in the power of the engines was required. This was caused by the fact that the longitudinal configuration -- analagous to tandem design in airplane construction -- has a lower aerodynamic quality. As a result, the (longitudinal) configuration concedes advantages to the single-rotor design with regard to range, economy and altitude. It is however, appropriate to point out that in hovering regime and with regard to static ceiling, this (longitudinal) configuration is superior to the single-rotor. At present, the company is building a new model -- the Bristol-192 -- with more powerful engines.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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In the United States, for a period of more than four years, designer Piasecki worked on a new, heavy helicopter of longitudinal configuration with a gross weight of 16 (metric) tons. After a disaster in 1956, work on this helicopter was stopped.

In view of the great difficulties encountered in developing helicopters of longitudinal configuration abroad, the Soviet dual-rotor Yak-24 helicopter represented a big achievement (Illustration 7).

Helicopters of coaxial type designed by N. I. Kamov (Illustration 8) are also being developed in our country. This design has advantages in controllability owing to greater symmetry and somewhat higher weight efficiency than a single-rotor design.

In foreign countries, notwithstanding the many attempts to bring coaxial helicopters to the point of practical utilization, nobody has yet succeeded in doing it. Therefore, the helicopters of M. I. Kamov will in the very near future make their appearance as the pioneer coaxial helicopters in actual use.

Use of Helicopters in the National Economy

Created at the price of great labor, helicopters have finally gone into practical use. Utilized first in the Army, they have, during recent years, begun to find ever wider use in the national economy.

In 1954, for the first time in the history of mastering the Arctic, helicopters appeared at the North Pole. These were Soviet Mi-4 helicopters which had flown from Moscow to the area of the North Pole -- a distance of

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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more than 7,000 kilometers. For a period of 13 months, in daytime and polar night, in snow storms and the strongest winds, these helicopters operated without fail, carrying scientists engaged in research work to adjacent ice floes. With their aid, sometimes dozens of kilometers from the polar stations, sites for landing airplanes were selected. From the airplane landing sites these indefatigable machines delivered men and cargo to the small ice pack areas containing the polar stations. Frequently during the polar night helicopters saved men and equipment by transporting them from breaking-up ice fields to a safe place. The honor of Heroes of the Soviet Union was awarded to Comrades Melnikov and Babenko, helicopter pilots who spent the first winter at the North Pole stations.

The expedition to the Antarctic in 1955 aboard the diesel-electric vessel "Ob" also was equipped with Mi-4 helicopters. These helicopters operated unfailingly -- easing to a huge degree the work of the researchers. Thus, for example, an overland expedition from the Mirny settlement to Oasis would require several weeks of hard going. But with the help of a helicopter the trip was made in only a few hours.

The exploitation of helicopters is being mastered on an ever wider scale. Characteristic is the trip of pilot comrade Koloshenko. Having flown at the beginning of 1956 from Moscow to the station North Pole No. 6, he made flights there during this station's entire period of drifting. Then when the station finished its work, pilot Koloshenko flew 740 kilometers over the open ocean in the same helicopter and returned to the mainland. At the present time, comrade Koloshenko is at the other end of the world, in Antarctica, in the same Mi-4 helicopter where he is serving the needs of the expedition at the Mirny settlement. Pilots I. Inozemtsev and

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N. Shonin operated their helicopters in the Antarctic the entire period between major overhaul. Only the crew -- two men -- serviced the helicopters.

Use of helicopters for geological surveying work has acquired especially great significance. Helicopters' unlimited abilities to deliver people to any point in the taiga, swamp, tundra or on a mountain range have reduced by many times the duration of geological survey work. What formerly required no less than a year is now accomplished with the aid of helicopters in several weeks. Helicopters' ability to follow exactly the terrain's relief in mountainous areas, and also the low flying speeds, permit use of new su   ying methods (gravimetric, etc.), which formerly could not be used in airplanes. These characteristics of helicopters have already led to a number of large and important discoveries.

Utilization of helicopters has changed the very character of geologists' work. Instead of a nomadic life in tents they can in a great many cases fly to a population point for the night.

The organization of helicopter rescue service has also become very important. Even without being specially equipped, Mi-4 helicopters, in case of necessity, have carried sick or injured persons and frequently expectant mothers from inaccessible areas to hospitals, where they received skilled attention. The employment of helicopters to rescue the population and deliver food and fodder during the spring flood at Rostov-on-Don in 1956 (Illustration 10) is widely known.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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In the very first months helicopters were used for rescue service in the Far East, at the end of 1956, Mi-4s saved over 100 human lives. In the spring of 1957, during the flood in the Urals, helicopters saved hundreds of people.

During a storm, the crew of comrade pilot Ageyev took off the entire 24-man complement of a trawler that had hit a rock. Ships couldn't approach the reefs in that stormy weather in which the trawler was wrecked, and a launch from the trawler was smashed. After the helicopter, hovering in the air over the ship's masts, had raised the last sailor by a rope ladder, the ship sank. Repeatedly helicopters have come to the aid of geological parties which had gotten into a difficult position. When ice closed the Amur in the fall of 1956, 65 Chinese explorers in the taiga were found and saved.

Helicopters do a great deal of cargo transportation. In this work their actual accomplishment is more vivid than any imagination. In 1956 helicopters carried live fish to stock new reservoirs and live sables to populate the taiga. Hunters were even carried into Kamchatka's inaccessible volcanic regions for the hunting season and then flown out. Besides this, helicopters perform conventional but no less necessary transport work.

Mi-1 helicopters are also used for mail pickup and delivery and for medical service (Illustration 11). In a large number of areas they are indispensable. In the years immediately ahead, the number of postal routes will be considerably expanded. The Mi-1NKh helicopter has detachable, suspended equipment which makes possible ambulance and mail transportation and the performance of agricultural work.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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There is also a broad field for helicopter activity in the agricultural economy — in the fight against field, orchard and forest pests. Mi-4S helicopters specially equipped for such purposes have operated successfully in orchards on the slopes of the Ala-Tau. These same helicopters are used in the Kemerovo taigo to fight ticks which carry encephalitis (Illustration 12).

The scope of this pamphlet does not permit a more detailed account of other fields where helicopters can be used as, for example, in evaluating timberland, fire fighting, for patroling high tension electric transmission lines, and for many other purposes.

The Economics of Helicopter Transportation

Despite broad areas of special use, the main purpose of helicopters will be for cargo and passenger transportation.

And this purpose will be widely achieved only when helicopter transport becomes economically profitable.

In this connection, three indices acquire great significance: the cost of carrying a passenger for one kilometer, the cost of carrying a one-ton load the same distance, and, finally, the cost of operating a helicopter for one hour — for machines which perform some work not associated with transportation of people or cargo (for example, patrolling forests or high voltage lines).

The main elements in operating costs are:

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

(a) Depreciation — the cost of the helicopter and engine must be paid for during the period that it can be kept in service.

(b) The cost of its repairs during this time, the number of which is determined by the relation between the depreciation period and the "resource" — the length of the period of operation between repairs.

(c) The servicing costs.

Further, the full wages of the crew (usually a pilot and mechanic), which also relate to each hour of flight, are taken into account. Here, of course, we assume some standard number of hours of flight per year. Then we consider the hourly expense for fuel and lubricants. Finally, there are the so-called station and line costs for ground service and various overhead expenses (organizational, radio communications, etc.), which can be estimated at 20 percent of the sum of all the previously enumerated costs.

The cost per hour of flight is determined in this way. If we apportion the cost according to the number of passengers carried or the weight of cargo and the cruising speed — that is, the number of kilometers flown per hour — then we will get the cost per passenger-kilometer or per ton-kilometer.

In order to estimate the economic indices of helicopter transportation, Table 1 is cited. In it are the approximate figures which can be achieved in the next 2-3 years. Also cited in the table are data for small, jet helicopters.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Table 1

COMPARATIVE COST ESTIMATES FOR OPERATING HELICOPTERS

Type of Helicopter	Transport Weight 7,000 kg.		Liaison Weight 2,000 kg.		Light	Weight 1,000 kg.
Drive Arrangement	Mechanical		Mechanical		Mechanical	Jet
Engine	Piston	Turbo-prop	Piston	Turbo prop	Piston	Turboprop with Compressor drive
Depreciation cost per hour of flight (rubles).....	400	400	166	166	106	80
Current repair (rubles)........	40	40	20	20	10	10
Crew wages (rubles)............	80	80	70	70	60	60
Station-line expenses (20%) (rubles)..............	132	130	59	60	40	41
Weight of fuel.................	200 kg. gasoline	280 kg. kerosene	60 kg. gasoline	100 kg. kerosene	30 kg. gasoline	120 kg. kerosene
Cost of fuel and lubricants (rubles).............	138	131	41	47	21	56
Cost per hour of operation (rubles)..........	790	781	349	363	237	247
Cruising speed, kilometers per hour..................	160	180	135	160	120	100
Number of passengers...........	12	16	3	5	2	2
Payload (kilograms)............	1,600	2,000	300	500	—	—
Cost per ton-kilometer.........	3 rubles 8 kopeks	2 rubles 17 kopeks	8 rubles 80 kopeks	4 rubles 54 kopeks	—	—
Cost per passenger-kilometer	41 kopeks	24 kopeks	88 kopeks	45 kopeks	98 kopeks	1 ruble 24 kopeks

Translator's Note: Conversion rate of rubles into dollars is variable. Official rate is 4 rubles per dollar. Tourist rate is 10 rubles per dollar, which is closer to actual buying power compared to dollar. There are 100 kopeks in a ruble.

See page 28B for table showing actual operating costs for Russian lightplanes and small, older transports used by Aeroflot.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Table 2

COST OF OPERATING LIGHT AND TRANSPORT PLANES

Cost	TYPE OF AIRPLANE			
	Po-2	Yak-12	An-2	Li-2
Per hour of operation	200 rubles	300 rubles	750 rubles	1,200 rubles
Per ton-kilometer	12 rubles 50 kopeks	11 rubles 50 kopeks	4 rubles 70 kopeks	3 rubles 48 kopeks
Per passenger-kilometer	2 rubles	1 ruble 15 kopeks	50 kopeks	33 kopeks

Translator's Note: The Po-2 is a single-engine, open-cockpit biplane with 100 mph. top speed. First flown in 1927, it is still used on Aeroflot's local air routes. The Yak-12 is a fairly modern, postwar, single-engine, light monoplane. The An-2 is a single-engine, postwar biplane capable of carrying 10 passengers or 2,600 lbs. of cargo. It is the workhorse of Russian local carriers. The Li-2 is the Russian version of the American C-47 but usually accommodates only 15 passengers. For purposes of this table, Mil rates the Po-2 as a one-passenger plane and the Yak-12 as two-passenger. Capacity of the An-2 and Li-2, as used in this table, is not given.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

These approximate computations are based on a period between helicopter overhauls of 500 hours, a depreciation period of 3,000 hours and 700 hours of flying per year. We will also assume that the cost of five repairs (overhauls) is equal to the total cost of the helicopter.

It should be mentioned that the cost of the mechanical assemblies -- reducers, shafts, hub, automatic swash plate, tail rotor and others -- which are being manufactured by motor factories, constitutes only 20 percent of the cost of a helicopter. From this it follows that with a future increase in the number of machines (helicopters) turned out at the main plant and with greater mechanization of so-called "aircraft" construction, the cost of helicopters in the future will decrease considerably.

We will assume that the crews contemplated in Table 1 consist of two men. The present cost of providing a ton-kilometer of cargo or a passenger-kilometer of transportation by means of light planes and transport planes based on our average overall costs per hour of operation in 1955, is shown in Table 2.

Here it was assumed that the Po-2 (lightplane) carries only one and the Yak-12 (lightplane) two passengers (for the same 400-kilometer distance).

In comparing these two tables we see that the costs of operating helicopters in the next 2-3 years, by means of a gradual decrease in the cost of helicopters and engines, an increase in the overhaul and depreciation period, and also by increasing the intensiveness of utilization (flying hours per year) can be reduced to the cost of operating airplanes. At the present time these (helicopter) costs are a little more than twice as high as for the planes with which they are compared.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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The fact that helicopter transportation is still more expensive than airplane transportation in no way limits the expediency of employing helicopter transport.

Helicopters must be compared with the type of transport that can be used under given conditions. For example, in the tundra, where it is not always possible for airplanes to land, the helicopter's competitor is the reindeer team which costs 200 rubles per ton-kilometer. The daily cost of operating an ice breaker comes to tens of thousands of rubles and often two ice breakers (one protecting the other) spend weeks pushing through the ice in order to deliver only 50-60 (metric) tons of cargo to winter-bound persons. In such a case, helicopter transportation is tens of times cheaper.

Under conditions encountered in the vast areas of the Siberian forests, the helicopter even when operated at today's costs is thoroughly profitable. The existing demand for helicopter transportation considerable exceeds the capacity of the fleet on hand. And yet the use of helicopters has only just begun.

From Table 1 it also follows that in the next few years helicopters -- especially those with turboprop engines, will not be inferior in economy to airplanes of similar power when flown over short distances. And, in addition, in a large number of cases where there are roadless areas, helicopters will also successfully take the place of light automobile transportation.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

This is easy to imagine if it is recalled that a kilometer of travel in a "Pobeda" taxicab costs 1 ruble 50 kopeks or, assuming a comparatively-long taxi trip with an average load of three passengers, the cost per passenger-kilometer comes to 50 kopeks.

With a six-place helicopter having a gross weight of 2,000-2,500 kilograms, this (passenger-kilometer) cost will be only 45 kopeks, and with a 16-place helicopter it will be only 24 kopeks.

Judging by the magazines, the Americans have set before themselves the task of achieving a helicopter operating cost of 10 cents per passenger-mile (or 33 kopeks per passenger-kilometer when converted into our currency). This, obviously, can also be achieved by us in the next few years (see Table 2).

There are at the present time several regular passenger and mail routes in foreign countries which are served by helicopters. In New York, helicopters provide connections between three airports. As compared with automobiles, the helicopters save time in taking passengers through the city or into the center of the city. In Europe, similar routes operated by the Sabena Company connect cities in Holland, Belgium and West Germany. A Paris-Brussels line connecting the centers of these cities has also been opened. All the helicopter lines in the Unites States and England operate under subsidies from the government.

Organization of regular (helicopter) routes in our country is a very important problem. In such places as the Black Sea coast, transportation from Sochi to Batum and from Simferopol to Yalta would be cheaper by helicopter than by auto even at present costs. The distance by highway between Yalta and Simferopol — about 160 kilometers — is covered in 2-1/2 hours by automobile.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

The air distance between these points is 50 kilometers and is covered in 20 minutes by helicopter. As soon as operation of helicopters is mastered sufficiently well and as soon as the necessary personnel cadres are created in Aeroflot (the Soviet civilian airline monopoly — translator) such helicopter routes will be opened.

Military Use of Helicopters

During the war in Korea and the colonial war in Malaya, helicopters were already used widely. With their help, wounded were transported; crews who had jumped by parachute from planes which were knocked down behind the front lines or fell into the sea were saved; liaison was established; artillery spotting was done, communications lines were set up, etc.

The maneuvers conducted by Americans in the Yucca (Flats) desert in 1953 in connection with an atomic bomb explosion provided for landing a battalion of troops with the help of 39 helicopters. The first party of troops was already in the air at the moment of the explosion and could select its course with consideration to the movement of the radioactive clouds and also could select the landing site after gaging the degree of contamination in the area.

It is natural, as foreign literature asserts, that use of helicopters to a great degree permits employment of the surprise element when an atomic strike is made against an enemy during an advance.

Experience gained in Korea showed the great significance of helicopters in maneuvering men on the battle field. Emergency shifting of reinforcements to a threatened sector of the front in mountainous terrain when roads leading

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

to the front were blocked was easily done with the help of helicopters. Exercises were conducted with regard to carrying multiple rocket launchers right on the battle field. In the event the enemy discovered the location of such a battery, the rocket launchers were suspended from the outside of helicopters and quickly moved to new positions.

Attempts were made in France recently to install guided "air-to-ground" type missiles on helicopters.

Helicopters continue to be used for landing troops. After the naval landing by Americans from ships with the aid of helicopters in Korea in 1951, the English carried out a similar operation at the end of 1956 at Port Said during their attack on Egypt. In 1-1/2 hours S-55 helicopters carried 500 landing troops from an aircraft carrier to the shore. As was asserted in the British Parliament, helicopters with greater lifting capacity were urgently required for such operations.

Putting ashore naval landing forces by helicopter enabled the ships to maneuver at a known distance from the shore fortifications while the landing troops were set down in the depths of the enemy's defences.

There is no need to elucidate the possibilities of using helicopters in mountainous areas where well-located emplacements or troop units, delivered by helicopters, can delay an enemy advance or make it impossible.

Mention should also be made of the use of helicopters in street battles in Port Said where, as the newspapers reported, helicopters fired machine guns.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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Helicopters must be regarded as having great importance in forcing water barriers. In addition to being able to transport troops or material across rivers easily, helicopters can bring in parts and erect pontoon bridges.

Attention is also being paid in the British and French armies to the construction of small -- mainly two-place -- helicopters for communication and battle direction. In England the "Avro-Skeeter" was recently accepted for fitting out for such work, and in France the "Djinn" jet helicopter was accepted.

There is also a big opportunity for using transport helicopters as direct replacements for auto transport in carrying troops and combat material in mountainous areas. Many authors believe that the use of helicopters can introduce important changes in the operation of rear areas.

It is especially worthwhile to consider the problem of using helicopters in the Navy to combat submarines by finding them with "hydro-locators" lowered from helicopters with subsequent destruction by bombs. Helicopters also can be used for sweeping different kinds of mines. In addition, helicopters can be employed to carry radar antenna which is lifted above a ship, thus considerably increasing the viewing radius. Models of this type of helicopter are now being built in the United States.

An important consideration is the fact that the large fleet of helicopters necessary in wartime can be accumulated and widely used in time of peace in the national economy since helicopters become obsolescent considerably more slowly than airplanes.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

A similar idea is now being developed in Italy. Needing helicopters for rescue service in mountain regions where the population frequently suffers from avalanches, the government plans to subsidize private companies to organize inter-city passenger routes so that in case they are required the helicopters and their crews will be placed at the service of the state.

It is unthinkable for military units in a modern army to be lacking in the broad employment of the universal air transport -- the helicopter.

The Future Development of Helicopter Manufacture

In just what direction will helicopters be developed? Life itself points out the direction of development. Their use in the national economy continually pushes forward the problem of economy, that is, increased weight efficiency, simplification, and, consequently, a less expensive basic configuration, and a changeover to more progressive, economically speaking, power plants -- increased cruising speed, increased reliability, safety and period between overhauls.

The problems of military application require construction of helicopters with ever greater lifting capacity since the items of military technology from heavy pontoons to tanks need such a medium of transportation as helicopters. In this regard, weight limitations still depend on the engineering art and on operational difficulties. At the same time, neither civil nor military use of helicopters presents problems of maximum speed, altitude or special range for helicopters. Here we do not have the competition that is normal in airplane construction between bombers and fighters for speed and altitude. There are not even the strategic considerations which stimulate increased range for airplanes.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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The helicopter cannot break away from its aerial foes, nor can it engage in combat with them. It must be covered from above by fighters. Therefore, helicopter development will more closely resemble the development of means of ground transport.

It is possible to expect that in the very near future helicopters will be employed to a large degree for transport purposes. In this connection, certain definite types or, more precisely, classes of machines will be established, just as has been the case in auto transport (see Table 3). Only modified basic types of this or that class will then be adapted to perform various special jobs, just as a basic type of truck is adapted for carrying milk or to clean the streets.

How will the power plants for helicopters be developed?

We know that in aviation the process of replacing engines goes on without interruption. Thus, for example, piston engines are being replaced by more advanced turboprop engines. It is possible that gas turbine engines will be replaced by direct flow and nuclear engines.

If for airplanes the fuel consumptions of piston and gas turbine engines is about the same, then for helicopters, which have lower flight speeds, this relationship is against gas turbine engines.

The fuel expenditures per horsepower for gas turbine engines on helicopters are substantially higher than for piston engines. The advantage here is achieved through the considerably decreased weight of the (gas turbine) engines themselves which, at the very same gross weight for the whole machine

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

increases the useful load.

In addition, on helicopters with a useful load of more than five metric tons it is not considered expedient to install piston engines because of weight considerations. Therefore, on such helicopters, turboprop jet engines will be used as a rule.

Representing a different direction in helicopter development from the standpoint of simplifying their basic configuration are the jet helicopters, whose lifting rotor is activated not with the aid of a motor which turns it through a reducer installed in the fuselage but by means of thrust developed by jet engines located right on the ends of the blades. Such a jet rotor does not have torque and turns freely on the axis. For this reason, such a helicopter does not need a tail rotor and a long transmission to activate it since the tail rotor on single-rotor helicopters serves to compensate for the reactive moment.

Several types of jet helicopters are known. The most common arrangement is that in which an engine installed in the fuselage turns a compressor. The air compressed by this compressor is directed into the hollow rotor blades and ejected through nozzles at their ends. The French "Djinn" helicopter (see Illustration 6) can serve as an example.

Other arrangements contemplate direct installation of direct flow or pulse jet engines right on the blade ends.

Despite the fact that many types of jet helicopters have been built according to these plans and several of them fly well, they have not found wide use up to the present time because of the large fuel consumption.

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

The simplest and at the same time least economical in fuel expenditure are the jet helicopters with direct flow engines. Pulse jet engines have somewhat smaller fuel consumptions, but they are extremely noisy. This sound of the engines is so piercing and annoying that their use on a passenger helicopter is practically impossible.

As for the compressor arrangement, here the long, crooked tract through which the air goes from the compressor through the blades to the jets located on the blade tips causes large resistances, and this sharply decreases the efficiency of the entire system.

Despite their large fuel consumption, modern jet helicopters of the compressor or other type can be used to advantage in a number of cases when only a small duration of flight is required. For example, they can be used by the Army for communications within a sub-division, as so called flying cranes, on which considerable work is now being done abroad, and for doing agricultural work as part of the fight against crop pests where the flight is very short, etc.

There can be no doubt, however, that in the next few years more active work will take place regarding construction of jet helicopters. A more widespread use of jet helicopters depends on the developement of jet engines that are more economical in fuel consumption and can operate on the blade tips. Such engines could be gas turbine types.

Despite the technical complexity of such a solution, which requires elimination of the gyroscopic moment from the quickly-turning compressors and turbines and the achievement of durability which would permit the engine to operate in

Approved For Release 2009/06/01 : CIA-RDP80T00246A010600700002-5

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a field of sizable centrifugal forces, this answer is very alluring and promising. As yet not one helicopter has been built according to this arrangement.

It should be mentioned that increasing the size of helicopters above a gross weight of 40-50 metric tons with conventional mechanical drive is already becoming difficult because of the need to build gigantic reducers.

With the construction of still bigger helicopters, the jet design can become uniquely possible.

Convertiplanes

Many people are distrubed by the question: isn't the modern helicopter only a transitional configuration in the history of aviation, like the autogiro? Won't they be replaced in the future by some apparatus which combines the characteristics of helicopters and airplanes?

Even in the first days of helicopter successes the idea emerged of combining the capability of vertical take-off and landing achieved in helicopters with the high speed, range and economy of airplanes.

The most varied combinations of such flying machines have been considered, but all of them, of necessity, include both a wing and a rotor.

Meanwhile, vertical-flying airplanes which dispense with any rotor have also appeared recently.

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Calculations show that supersonic airplanes which fly at a speed of 2,000 kilometers per hour and more have engine thrust to overcome aerodynamic drag practically equal to and even greater than the weight of the entire airplane. Naturally, such an airplane can also take off vertically if, for example, it is placed nose upward.

In this way it is possible to solve the very acute problem for military aircraft of intercepting bombers in places where there are no airports. By temporarily deflecting the thrust of their jet engines downward, it may be possible in the future to solve the problem of enabling even supersonic bombers to take off without a take-off run.

But is it possible to employ such a solution for transporting passengers and cargo for short distances up to 500 kilometers -- that is, for the job which helicopter transportation does? Of course not. And this is not only because such huge speeds are unthinkable for short distances but also because of economic considerations. In a modern fighter plane which can take off vertically, engines with a total power of approximately 20,000 horsepower are installed, whereas a helicopter of exactly the same weight can fly with total power of only 1,000-1,500 horsepower, or one-tenth to one-fifteenth as much.

We will take a look to see what the power expended to support one kilogram of a device's weight in the air depends on.

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The law of mechanics is known which says that an impulse of force is equal to the amount of motion. That is, the force developed by some reactive apparatus, a propeller in particular, is equal to the product of the air mass multiplied by the additional speed which is imparted to this air. But the air mass on which the propeller acts depends on the volume of air that flows through it, that is, upon the produc of the disc area by the speed of flow.

This law in the given case can be expressed as:

$$T = \pi R^2 vp.2v = 2\pi R^2 pv^2$$

The first three terms represent the volume; multiplying it by p — the air density — we get the mass. The term 2v represents the speed of flow which is applied to this mass of air beyond the propeller surface. The coefficient 2 is introduced because the speed of repulsion, owing to compression of the stream behind the propeller, is doubled.

Thus it is found that the greater the diameter of the propeller, the less need be the speed applied to the air (the induced velocity) that is required to support a helicopter's weight.

The power expended in creating the force is equal to the product of the force by the speed, that is:

$$N = Tv = 2\pi R^2 pv^3$$

This formula determines the induced power. But on an actual propeller, power is also expended in overcoming the profile drag of the blades which develops when the propeller turns.

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Assuming that the ratio of the profile power losses to the induced losses remains constant with a change in propeller diameter, helicopters of exactly the same weight but with different rotor radii will need power necessary to keep them in the air that is inversely proportional to the radii of their rotors.

For example, on a helicopter with a rotor diameter of 20 meters and an engine output of 1,500 horsepower it is possible to lift a load of 7,500 kilograms. But in order to lift the same load with a conventional airplane propeller (tractor propeller) 4 meters in diameter, 5 times as much power is required.

Putting it another way, if the rotor of a Mi-4 helicopter lifts per one horsepower $\frac{7500}{1500} = 5$ kilograms/horsepower, then a propeller with a diameter of 4 meters will lift only 1 kilogram/horsepower. This is a representative magnitude for the thrust of an airplane propeller _in situ_ relative to a unit of engine power.

We will now calculate the required power of engines which should be installed in a convertiplane and an airplane to ensure vertical takeoff and hovering over the ground. We will assume their weight to be 7,500 kilograms -- approximately the same as for the Mi-4 helicopter.

In converting the reactive thrust of the engines into comparison power in horsepower, a speed of 300 meters per second was used according to the formula:

$$N_{h.p.} = \frac{TV}{75} = \frac{7500.300}{75} = 30000 \text{ h.p.}$$

From this calculation it is apparent that an airplane which takes off vertically with the aid of engine reaction or of ordinary propellers cannot be suitable

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for lifting and carrying loads. It would be more rational to build a combination apparatus which has a large lifting rotor of the same diameter as that on a helicopter for vertical takeoff and landing.

The most logical arrangement for such an apparatus is represented by Fairey's "Rotodyne", an experimental copy of which is now being built in England. Here the large rotor for vertical takeoff and landing is driven by engines which, in horizontal flight, are changed over to drive tractor propellers. Flight is achieved in the same manner as with an autogiro: the wing creates a considerable part of the lifting force, and the rotor only carries a small part.

Work on the Fairey "Rotodyne" has already been carried on for three years. Even if such an arrangement should prove successful it is clear that the small gain in speed as compared with a conventional helicopter (on the order of 100 kilometers per hour) is purchased here at a high cost in load lifting capacity.

Ordinarily, the wing of an airplane weighs 15 percent of the gross weight. A lifting rotor with its drive and controls also weighs no less than 10-15 percent of the gross. On such an apparatus (as the "Rotodyne") there must be two separate lifting systems.

For takeoff and landing, the wing and empennage can in no way help the rotor, and at maximum speed the wing carries a large part of the loading. The superfluous weight of the second lifting system must be subtracted from the useful load, which, for both a helicopter and an airplane, constitutes 35-40 percent of the power. Thus the useful load of any convertaplane comprises at best only one-half of the useful load of a helicopter of the same power.

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The efficiency of a lifting rotor and engine is greater than the efficiency of a propeller. The lifting rotor permits lift to be created with less fuel consumption required by the engine. It may be stated that addition of auxiliary engines with tractor propellers or changing over part of the engines' power to tractor propellers with the purpose of converting to less loaded regimes for the lifting rotor or to a regime of autorotation will not increase either the economy of a helicopter or its cruising speed. A small increase in speed does not have great significance for a transport helicopter.

In certain cases, where economy is not a decisive factor, any kind of combined arrangement will be used. For example, the Fairey "Rotodyne" helicopters are intended for the Paris-London route.

In examining the problem of flight speed, it should be kept in mind that a helicopter of conventional design possesses still unused possibilities for increasing the maximum speed. With most modern helicopters, the maximum speed, and frequently also the cruising speed at altitude, are limited not by the power of the engines but by the effects of disruption of the air flow on the part of the blade which moves in the direction of flow, where large angles of attack arise. A whole series of ways -- by drawing off and blowing off the boundary layer, mechanization of the profile, and others -- still await utilization to increase the flying speed of helicopters considerably.

These simple considerations permit us to believe that for transporting people and cargo short distances (up to 500 kilometers) the most rational machine is, and will so remain for a long time, the helicopter in the form that we have it today.

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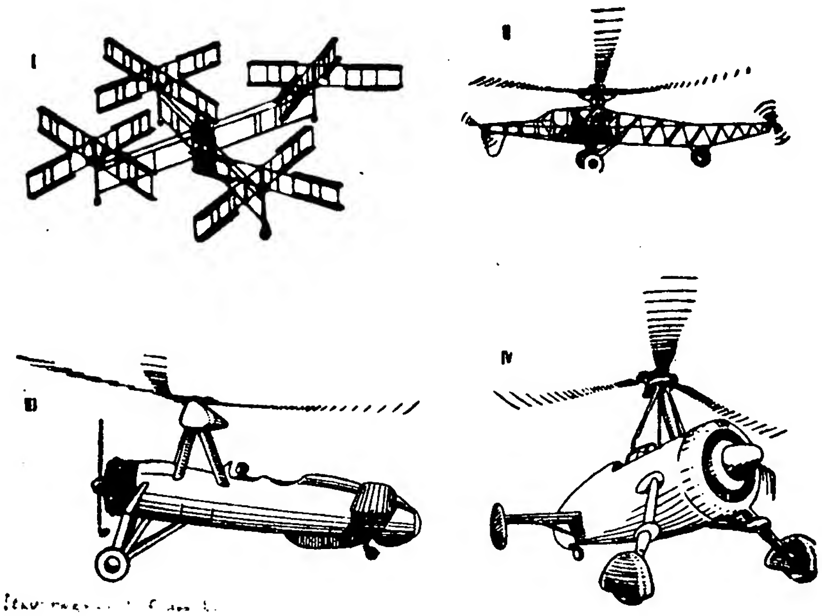

ILLUSTRATION 1.

FIRST HELICOPTERS AND AUTOGIROS

1 - Broguet and Riche

2 - EA-1

3 - C-30

4 - A-12

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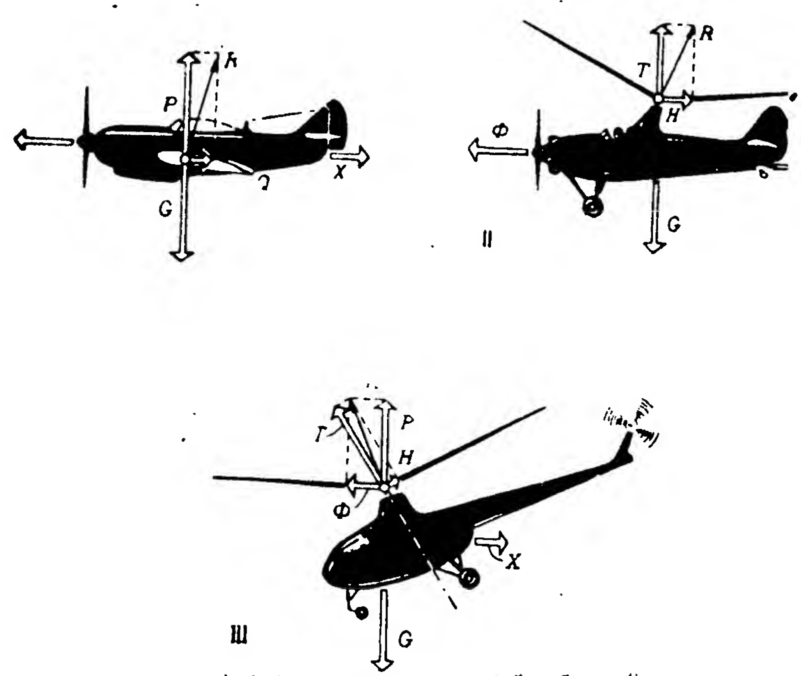

ILLUSTRATION 2.

INTERACTION OF FORECES IN FLIGHT

FOR DIFFERENT FLYING MACHINES

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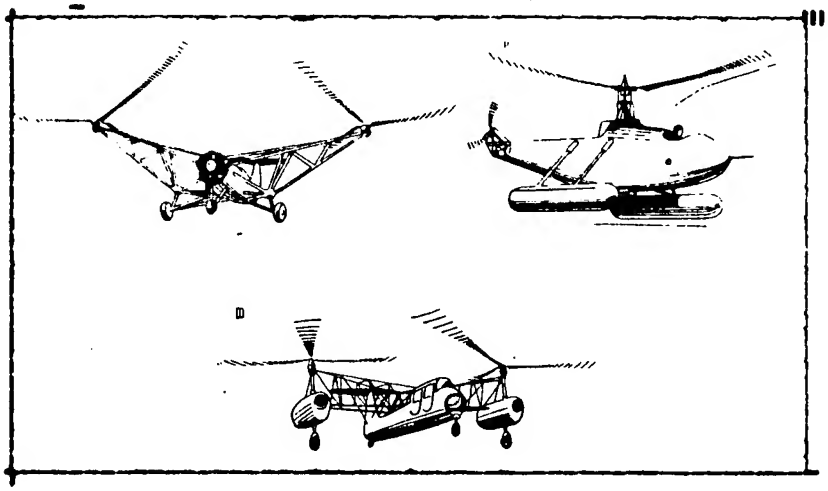

ILLUSTRATION 3.

FIRST EXPERIMENTAL HELICOPTERS

IN WHOSE CONSTRUCTION THE EXPERIENCE OF AUTOGIRO BUILDING WAS USED

1. Focke - Wolfe

2. VS-300

3. "Omega"

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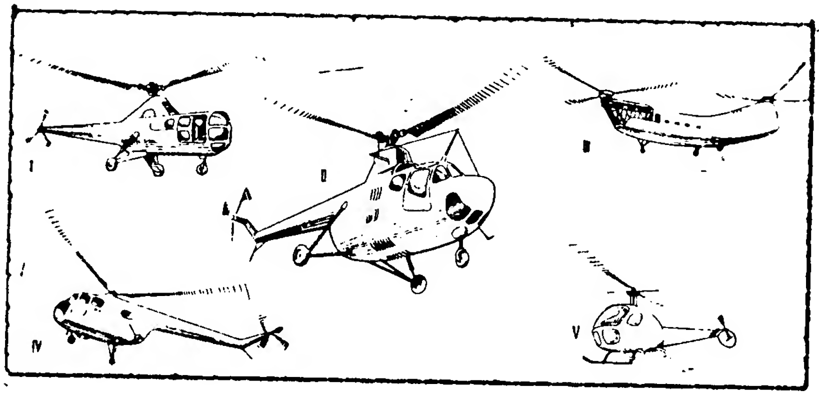

ILLUSTRATION 4.

FIRST QUANTITY-PRODUCED HELICOPTERS PUT INTO PRACTICAL USE

1. S-51

2. Mi-1

3. Piasecki Helicopter

4. Bristol "Sycamore"

5. Bell-47

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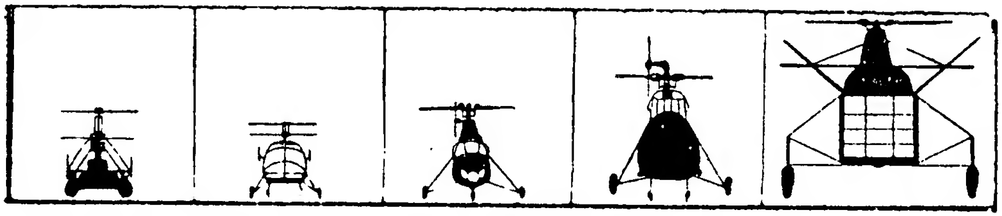
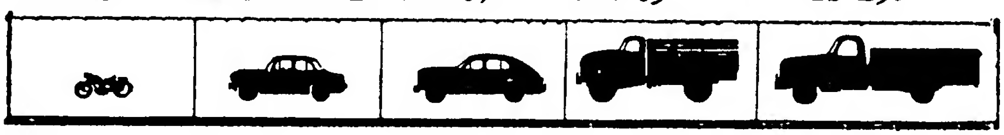
TABLE 3

TYPE OF HELICOPTER					
	One-Two Place	Two-Three Place	Four-Five Place	12 Persons or 1.5-2tns of cargo	2-3 tons
POWER OF ENGINE IN H. P.	55 -100	200-250	500-600	1500-1700	1700 X 2
TAKEOFF WT. IN KILOGRAMS	400-600	1000-1400	2000-2500	5800-7500	13000-16000
TYPICAL REPRESENTA-TIVES	KAMOV KA-10	KAMOV KA-15 - BELL 47	MI-1 S51 BRISTOL-171	MI-4 S-58 H-21	YAK-24 S-56
EQUIVALENT AUTO TRANSPORT	MOTOR-CYCLE	SMALL AUTOMOBILE	"POBEDA" GAZ-69	GAZ-63	ZIS-150
					

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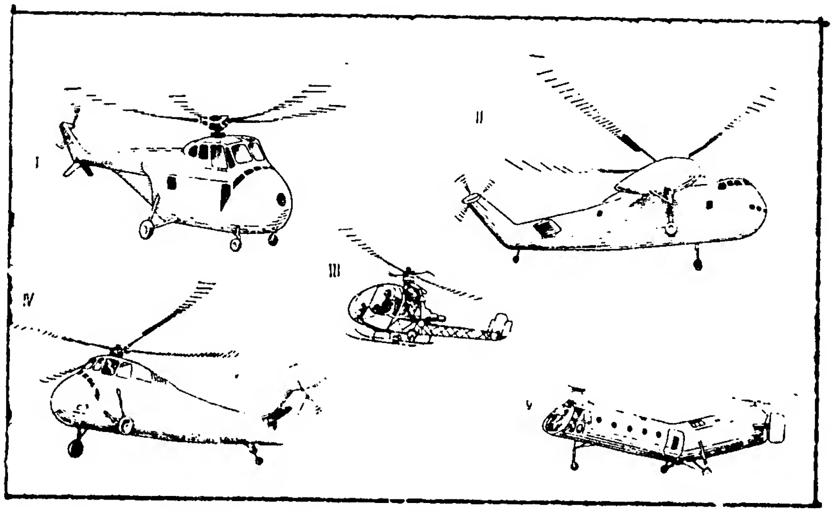

ILLUSTRATION 6.

MODERN FOREIGN HELICOPTERS

1. S-55

2. S-56

3. "Djinn"

4. S-58

5. H-21

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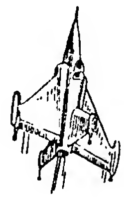
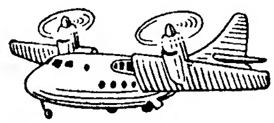
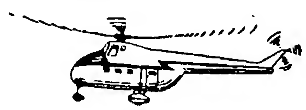
GROSS WEIGHT OF ALL CRAFT IS 7500 KILOGRAMS

Таблица 4

DESIGN OF CRAFT	Поднимаемый груз на единицу мощности двигателя / Load limited per unit of engine power	Расход горючего на единицу тяги или мощность / Fuel consump. per unit of thrust or power	Потребная тяга или мощность / Required thrust or power	Часовой расход горючего на режиме висения / Fuel consump. per hour in hovering regime
 JET AIRPLANES	0,25 кг/л.с. kg/hp	0,3 кг/л.с. kg/hp	30 000 л.с. hp	9 000 кг kilograms (kg)
 CONVERTIPLANE WITH SWIVEL WING AND CONVENTIONAL PROPELLARS	1 кг/л.с. kg/hp	0,25 кг/л.с. kg/hp	7 500 л.с. hp	1 750 кг kg
 HELICOPTER	5 кг/л.с. kg./hp	0,25 кг/л.с. kg/hp	1 500 л.с. hp	375 кг kg.

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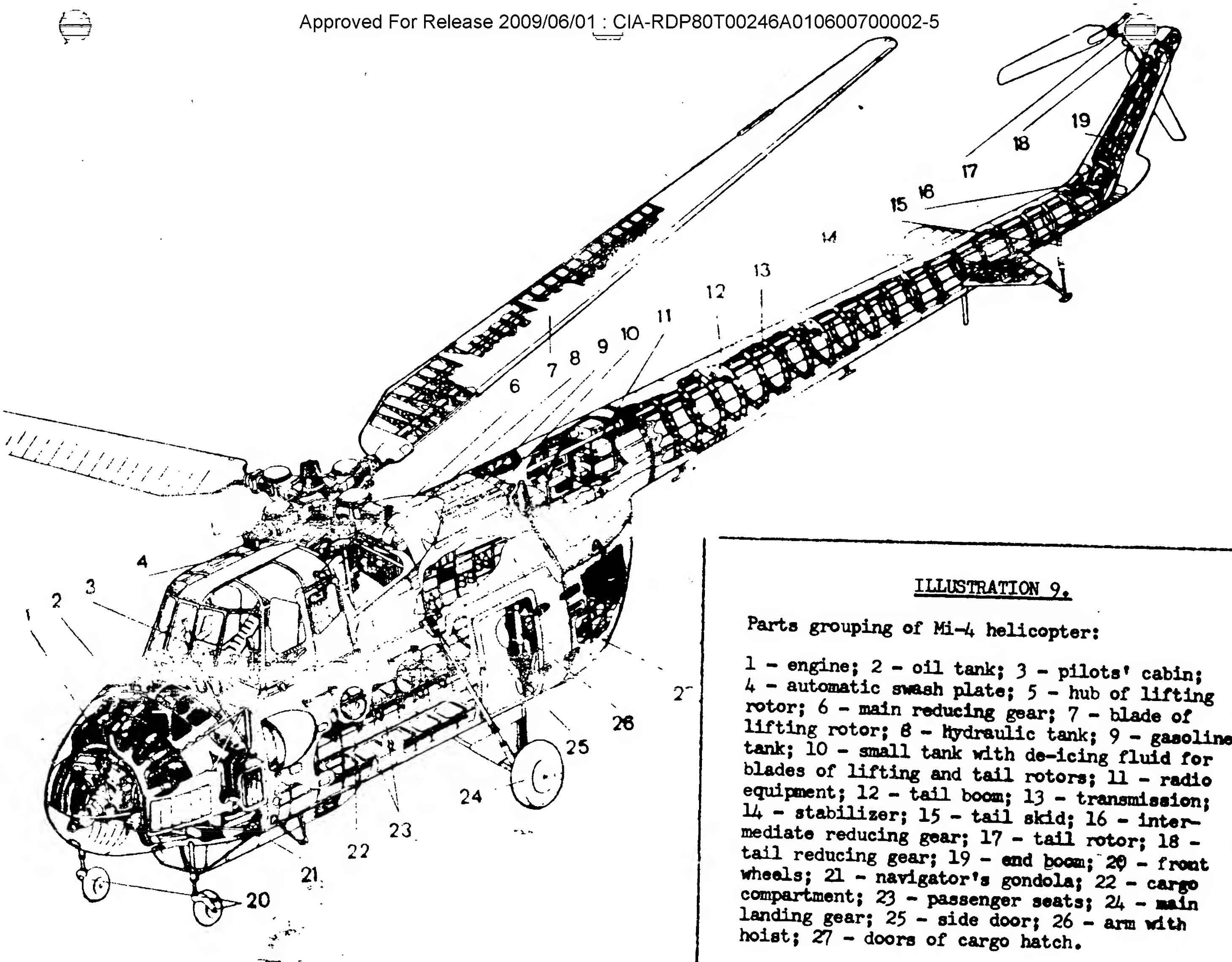

ILLUSTRATION 9.

Parts grouping of Mi-4 helicopter:

1 - engine; 2 - oil tank; 3 - pilots' cabin; 4 - automatic swash plate; 5 - hub of lifting rotor; 6 - main reducing gear; 7 - blade of lifting rotor; 8 - Hydraulic tank; 9 - gasoline tank; 10 - small tank with de-icing fluid for blades of lifting and tail rotors; 11 - radio equipment; 12 - tail boom; 13 - transmission; 14 - stabilizer; 15 - tail skid; 16 - intermediate reducing gear; 17 - tail rotor; 18 - tail reducing gear; 19 - end boom; 20 - front wheels; 21 - navigator's gondola; 22 - cargo compartment; 23 - passenger seats; 24 - main landing gear; 25 - side door; 26 - arm with hoist; 27 - doors of cargo hatch.

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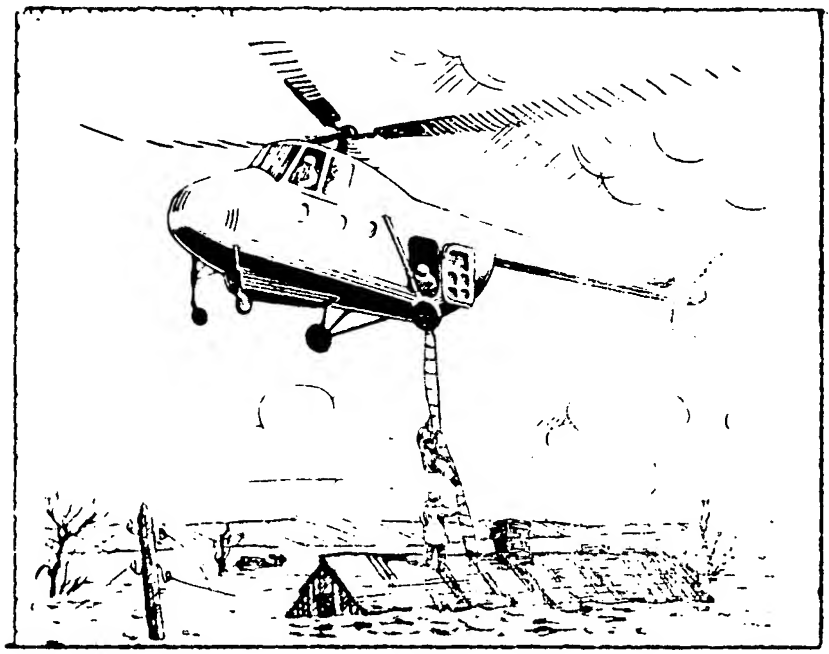

ILLUSTRATION 10

Mi-4 HELICOPTER PERFORMS RESCUE OPERATIONS DURING A FLOOD

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